

Investigation of a hybrid structure gaseous detector for ion backflow suppression^{*}

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Abstract: A new concept for ion backflow suppression in future time projection chamber with Micropattern Gas Detectors readout is presented. It is a hybrid structure cascaded Gas Electron Multiplier with Micromegas with the goal to reduce ion backflow from the amplification region towards the drift volume. Gas Electron Multiplier also acting as a preamplifier and shares gas gain with Micromegas. In this way a lower voltage difference has to be applied to the Micromegas and risk of sparking is reduced. Feasibility tests for the hybrid detector is performed using an ⁵⁵Fe X-ray source to evaluate the energy resolution, its gain properties and the ion backflow. The energy resolution is better than 27% FWHM for 5.9 keV X-rays. It is demonstrated that at a gain up to 6000, a backflow ratio less than 0.3% is reachable in the hybrid readout structure.

Key words: Micro Pattern Gaseous Detector (MPGD), Gas Electron Multiplier (GEM), Micro-mesh gaseous structure (Micromegas), Ion Backflow (IBF)

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1 Introduction

Time Projection Chamber (TPC) has been extensively studied and used in many fields, especially in particle physics, including STAR[1] and ALICE[2]. Its low material budget and excellent pattern recognition capability make it an ideal device for three-dimensional tracking and identification of charged particles. It is also the only electronically read gaseous detector delivering direct three-dimensional track information[3]. However, There has always been a critical problem with TPC, especially in high background conditions, which is the space charge distortion due to the accumulation of positive ions in its drift volume. Due to its large mass, positive ions move slowly under the action of electric field in the drift volume of TPC. The continuously superimposed ions in the drift volume of the TPC may affect the drift behaviour of the electrons from a later track[4]. The majority of ions inside the drift volume are backflowing ions from amplification region of TPC readout devices. It is thus of great importance to limit ion backflow (IBF) from the amplification region.

The early TPCs are equipped with Multi Wire Proportional Chambers (MWPCs)[5] as gas amplification devices. The IBF ratio in a standard MWPC is 30-40%[6],

so a gating grid is essential to prevent ions from reaching the drift volume[7]. In the presence of a trigger, gating grid switches to open state to allow the ionization electrons passing into the gas amplification region. After the maximum drift time of about 100 μ s (depending on the drift length, electric field and gas mixture), gating grid is closed to prevent positive ions from drifting into the drift volume. It is effective in suppressing IBF; however, its use presents challenges. Since it must remain closed until ions are collected on the grid wires, during this time, the ionization electrons are also blocked and a consequently dead time arise. Moreover, a triggered operation of gating grid will lead to loss of data. Thus, the TPC at circular collider will have to be operated continuously and the backflow of ions must to be minimized without the use of a gating grid.

TPC combined with MPGDs, especially Gas Electron Multiplier (GEM)[8] and Micro-mesh gaseous structure (Micromegas)[9], is very attractive, because IBF of the new readouts are intrinsically low which is usually around few percent. GEM detector has been extensively proved in the last decade to be the prime candidate as they offer excellent results for spatial resolution and low IBF[10]. Several GEM foils can be cascaded, allowing

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the multilayer GEM detectors to be operated at an overall gas gain above 10^4 in the presence of highly ionization particles. Micromegas is another MPGD that is likely to be used as end-cap detectors for the readout of TPC. It is a parallel plate device, composed of a very thin metallic micromesh which separates the detector region to a drift and amplification volume. To obtain sufficient amplification in the thin amplification gap ($\sim 100\mu\text{m}$), a electric field as high as $30\text{C}80\text{ kV cm}^{-1}$ is required. IBF of this detector is equal to the inverse of the field ratio between the amplification and the drift electric fields[11]. Low IBF therefore favours high gain. However, high gain will make it particularly vulnerable to sparking[12].

A TPC with excellent performance is required to fulfill the physical goal of the next circular collider. MPGDs are needed because of their outstanding single-point accuracy and multi-track resolution in projection. We proposed and investigated the performance of a novel configuration for TPC gas amplification: a combination of GEM and a Micromegas. The detector will be called GEM-MM for short throughout this paper. The aims of this study is to suppress IBF continually by eliminating gating grid.

This article describes a prototype GEM-MM detector. The detector design and the experimental setup are described in Section 2. The results of the detector performance tests and conclusions are given in Sections 3 and 4, respectively.

2 Experimental setup

The cascaded structure of the GEM-MM detector is composed of a drift electrode, GEM foil, standard Micromegas, and a readout printed circuit board. The Micromegas detector is based on the bulk method and has an active area of $25\text{mm}25\text{mm}$. The micromesh is a stainless-steel cloth mesh made by stainless steel wires of $22\mu\text{m}$ in diameter interwoven at a pitch of $62\mu\text{m}$. Its role is multiple, and does more than marking the end of the transfer region and the beginning of the avalanche one. Besides, it has also the capability to naturally stop most of the ions produced in the avalanche region during to the very large field ratio between the avalanche and the transfer regions. Under the micromesh with a distance of $128\mu\text{m}$ is a single copper pad readout plan. A GEM foil is cascaded above the micromesh and the distance between them is 1.4mm . It is a standard GEM foil of $25\text{mm}25\text{mm}$ from CERN. A drift cathode is mounted above the GEM foil. During the experiment, the drift distance is maintained at 4mm . The cascaded structure of the GEM-MM detector is composed of a drift electrode, GEM foil, standard Micromegas, and a readout printed circuit board. The detector and the drift cathode are biased using CAEN N471A high voltage unit. A ^{55}Fe source has been used to produce the primary electrons in

the sensitive volume during the test. The measurements are made in an Ar- CO_2 gas in the ratio 70-30 at room temperature and atmospheric pressure.

In the gain measurement (schematically shown in Fig. 1), the micromesh electrode is connected to a charge sensitive pre-amplifier (ORTEC model 142IH) and the anode pad is grounded. Subsequently, the output pulse from the pre-amplifier is fed to a amplifier (ORTEC model 572A) with a shaping time constant of $1\mu\text{sec}$. The data is finally recorded in a multi-channel analyzer (ORTEC ASPEC 927). To characterize the performance of GEM-MM detector, electronic gain is calibrated firstly. Under various GEM and micromesh voltages, ^{55}Fe spectra are then taken. The detector gains are available from the spectra with the calibrating result of electronic gain.

Ion backflow is known as secondary ions generated in an electron-avalanche process in the TPC return to the drift space. Throughout this paper, fractional ion feedback is defined as the ratio of the ion charge injected into the drift volume and collected on the drift electrode, to the electron charge collected on the anode pad. In the experimental test of IBF, currents on the drift cathode and the anode pad are measured as I_c and I_a respectively. I_c is proportional to the number of ions collected on the drift cathode. Positive charges collected on the drift cathode are primarily backflowing ions from gas amplification region (avalanche region and GEM hole), a contribution from ions created during the primary ionization process is also included. This part is not negligible since the backflowing ions current is very small under a ^{55}Fe source. So the primary ion current I_{prim} on drift cathode is also measured, as shown in next section. I_a is the current measured in the anode pad and proportional to the number of electrons collected on the anode. Finally IBF is measured as:

$$IBF = \frac{I_c - I_{prim}}{I_a} \quad (1)$$

For the measurement of current, an electrometer, Keithley model 6517B[13], has been used which can measure the current with 1pA resolution. Electrode to be measurement is at a grounded potential because of the electrometer constraints. For anode current measurement, the detector is biased with negative voltages, the further away electrode gets from anode, the more negative potential is biased. For the measurement of ionic current from the drift cathode, however, the detector must be biased with another voltage configuration. The drift cathode is grounded, whereas other electrodes have been biased with positive voltages to maintain electric field as the case of anode current measurements.

3 Measurement results and discussions

3.1 Energy spectrum

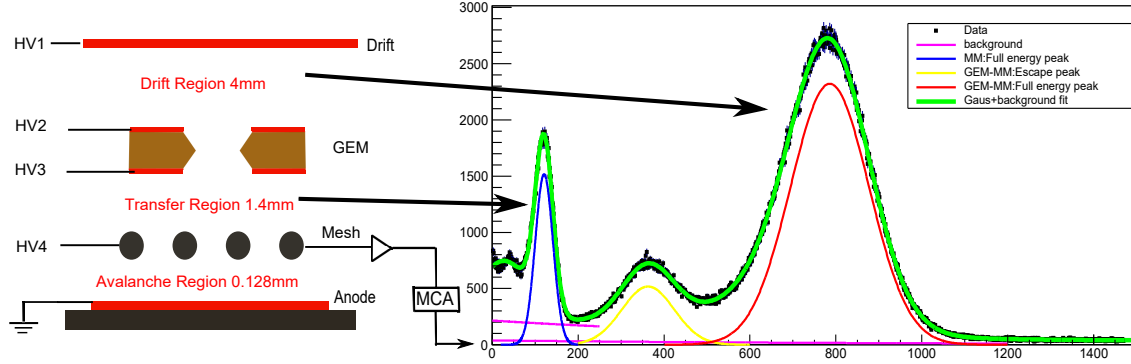


Fig. 1: GEM-MM configuration(left) and pulse height spectrum on 5.9 keV for a GEM-MM showing each peak and the corresponding location of primary ionization(right). Source: ^{55}Fe , Gas: $\text{Ar}(90)+\text{CO}_2(10)$, $E_d=250\text{V/cm}$, $V_{\text{gem}}=340\text{V}$, $E_t=500\text{V/cm}$, $V_{\text{mesh}}=420\text{V}$.

^{55}Fe X-ray source with a characteristic energy of 5.9 keV is used as the radiation source. In argon based gases, a typically pulse height spectrum of GEM or Micromegas detector contains one major peak corresponding to 5.9keV X-rays and an escape peak at lower pulse heights corresponds to the ionization energy of an electron from Argon's K-shell. In GEM-MM detector, however, things are different. There are two amplification stages inside this detector. Primary ionization created by photon absorption can be in drift region or in transfer region(Fig. 1). Photoelectrons starting from the drift region get amplified by GEM and Micromegas and end upon the anode. If photons are absorbed in the transfer region, primary electrons will experience amplification only once(by Micromegas).

Fig. 4 depicts a typical ^{55}Fe pulse height spectrum obtained with GEM-MM detector. Four peaks are seen in the pulse height spectrum. The first two are the escape peak and full energy peak of the pure Micromegas. And the last two are created by photons with their energy deposited the drift region. These primary electrons experience amplification twice. The principle of GEM-MM detector is fully verified.

Table 1: Gaussian fit results.

Peak	Mean	Sigma	Resolution(%)
MM Photo Peak	120.9	20.6	40.1
GEM-MM Escape Peak	362.9	60.8	39.4
GEM-MM Photo Peak	785.9	91.1	27.3

The spectrum is fitted with a Gaussian distribution to extract the mean and the sigma of the four peaks. Table 1. summarizes the gauss fitted mean and sigma values for three of the four peaks. For escape peak from Mi-

cro-megas only will always be submerged in noise, it is thus not well fitted as other peaks. Energy resolution of each peak(in FWHM) is also presented in the table.

3.2 Gain

With the calibrated electronic gain results, the gain of the detector is obtained from the measured spectra as described in the previous subsection. Gain of Micromegas, G_{MM} , is characterised by the first full energy peak in the spectrum(MM photo peak in table 1), and the last full energy peak(GEM-MM photo peak in table 1) represents the overall gain of GEM-MM detector, G_{GEM-MM} . So the effective GEM gain can be expressed as:

$$G_{GEM} = \frac{G_{GEM-MM}}{G_{MM}} \quad (2)$$

GEM is the first gain element in the GEM-MM detector, and its effective gain is a function of the voltage across the GEM. Similarly, the gain of Micromegas, the dominating gain element, is a function of voltage difference between micromesh and the anode. Keeping the drift field at 250V/cm(typical drift field for TPC), and the transfer field at 500V/cm, a set of measurements with various voltage settings give the gain curves displayed in Fig 2. As shown in the figure, the GEM preamplification helps GEM-MM achieve high gains with Micromegas working under relatively low voltages. The spark rates can be greatly reduced even at high gas gain. It is important to note that this is a new way to the measure effective gas gain of GEM. It is an effective method for gain measurement of GEM even with relatively low gain. A gain of about 6000 can be achieved without any obvious discharge behaviour.

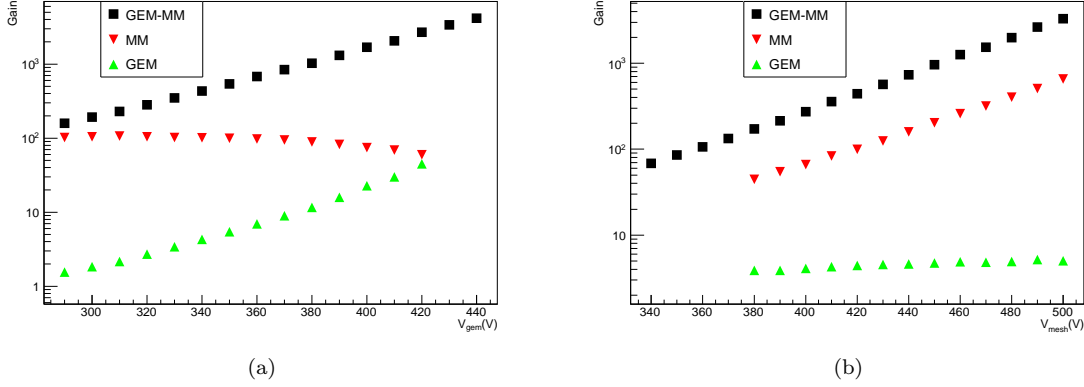


Fig. 2: Gas gain versus GEM voltage, micromesh $V_{mesh} = 420V$ (a) and micromesh voltage, $V_{GEM} = 340V$ (b). $E_d = 250V/cm$, $E_t = 500V/cm$

3.3 Ion Backflow

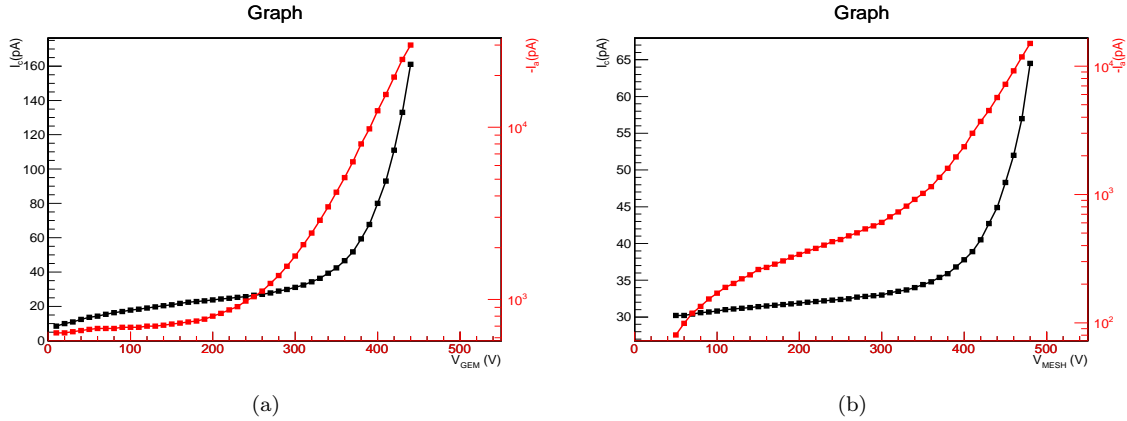


Fig. 3: Measured currents on anode(I_a) and the drift cathode(I_c) versus (a): GEM voltage, micromesh $V_{mesh} = 420V$ and (b): micromesh voltage, $V_{GEM} = 340V$. $E_d = 250V/cm$, $E_t = 500V/cm$

GEM plays an additional role, which is to reduce the ion backflow. In order to study the IBF of GEM-MM detector, the currents on its different electrodes are measured using an electrometer. With a precise measurement of the currents on the anode and the drift cathode it is possible to calculate the IBF (according to Eq.(1)) for different working conditions of GEM-MM. In Fig. 3, correlations between voltage applied on GEM (Fig. 3(a)) or Micromegas (Fig. 3(b)) and the currents measured on anode or the drift cathode are demonstrated. Fig. 4 shows the calculated IBF. Gas gain of GEM-MM detector are also plotted in the figure.

Note that in Fig. 3(a) and Fig. 4(a), voltage across the GEM foil begins with 10V and Micromegas is working normally. Excepting for primary ionization gener-

ated ions in the drift and transfer region, ions collected on the drift cathode are from the avalanche region of Micromegas detector. With the increase of GEM voltage, electron current on anode remains about the same before electron avalanche happens inside the GEM foil. Nevertheless, GEM foil will have an increasingly higher transparency for ions to pass through to the drift region, which means ion current on the drift cathode increases. Consequently, IBF increases along with the GEM voltage increased. However, gas amplification begins to occur inside the GEM hole as its voltage goes on increasing which has a positive effect on the increase of electron current on the anode. Therefore, IBF increases as the GEM voltage increases initially and decreases afterwards. So ion backflow values of 2-3% are considered to be the IBF

for a standalone Micromegas detector with a gain about 600. When GEM is cascaded, IBF can be further reduced

to value below 1%.

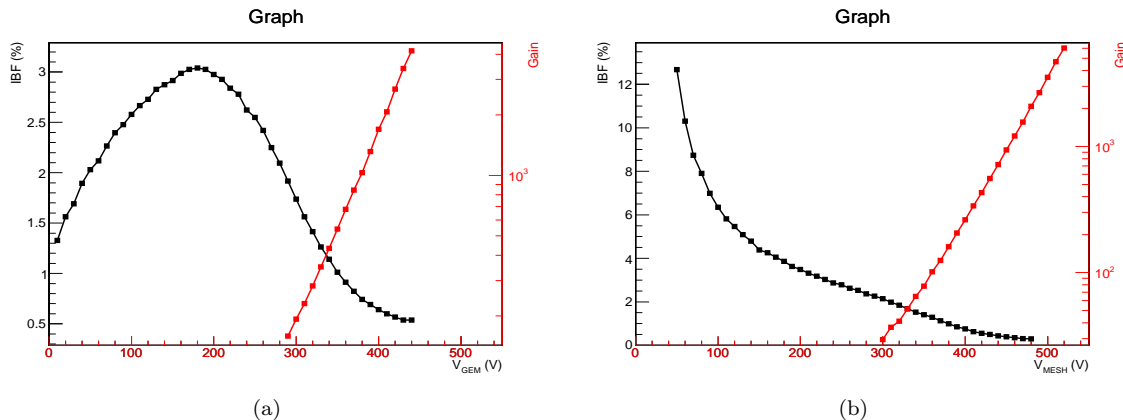


Fig. 4: Gas gain and IBF versus (a): GEM voltage, micromesh $V_{mesh} = 420V$ and (b): micromesh voltage, $V_{GEM} = 340V$. $E_d = 250V/cm$, $E_t = 500V/cm$

Fig. 4(b) shows that when a constant bias voltage across GEM is set, IBF decreases as micromesh voltage increased. The reason is that electrons collected on the anode increases with the increase of the mesh voltage. So proportion in a few percent can be estimated as IBF for a single GEM detector with a comparatively low gain of approximately 4. After Micromegas is cascaded, however, IBF is reduced significantly.

4 Conclusion

We presents a new concept for IBF reduction in the future MPGD readout based TPC, a prototype is de-

veloped. It is a hybrid structure with one GEM foil cascaded above the Micromegas detector. Tests of this detector have been carried out with an ^{55}Fe X-ray source in Ar- CO_2 (90-10) gas mixture. The gain properties of this device is measured. A gain up to 6000 can be achieved without any obvious discharge behaviour. The preamplification of GEM foil is apparent. Currents on the anode and drift cathode are measured precisely with an electrometer. IBF can be reduced down to 0.3% at a gain of 6000. TPC with this hybrid structure readout detector can be operated continuously without using gating grid. IBF, however, is suppressed continually.

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